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A Double Super-Ferric Ring (DSF-MR) in the Tevatron for a Neutrino Factory

Outline

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3. Possible detector sites for Fermilab long-baseline neutrino beams
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7. Tevatron infrastructure for use with DSF-MR
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Preliminary Note at:
http://tdserver1.fnal.gov/project/Nu-factory/DSF-MR.doc

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Motivation

- Startup of LHC in late 2007 brings end to the Tevatron
- ILC with its primary motivation to study Higgs must wait for Higgs discovery at LHC to determine mass reach
- Most theorists expect Higgs, or any other EW symmetry breaking mechanism, to appear at mass order of 1 TeV
- It is likely to take few years for LHC to confirm or deny existence of SM Higgs (M_{Higgs} < 0.8 TeV)
- The US high-energy physics community must have an intermediate, high-profiled, accelerator based program
- Intermediate program should be of moderate cost, so not to affect potential ILC construction if it becomes reality
- Long baseline neutrino oscillation physics matches well the requirements of high-profile and cost effectiveness

Physics potential of long baseline neutrino oscillation experiments

- As limits on Δ m(ν_α,ν_β) get smaller the baseline, L, must be increased as:

$$P(\nu_\alpha \to \nu_\beta) \sim \Delta m(\nu_\alpha,\nu_\beta) \times L \times 1/E_\nu$$

- At current longest baselines (750 km, or so), the interpretation of results is uncertain due to 8-fold degeneracy of theory parameters
- It has been shown recently that there exist baseline at which parameter degeneracy is suppressed, and e.g. angle Θ ($\nu_\mu \to \nu_e$) will be directly measured. This "magic" baseline depends only on matter density:

$$L\ \text{magic} = 32726 / \rho\ [\text{g/cm}^3] \Rightarrow \sim 7250\ \text{km}$$

for $\rho = 4.3$ g/cm^3 of Earth's density profile

- In addition, a combination of results at ~7500 km and ~3000 km allows to increase parameters sensitivity by > 3 order of magnitude

Experiment	Baseline [km]	$\sin^2 \theta_{13}$	δ_{CP}	Mass hierarchy
MINOS	735	> 0.05	NO	NO
CNGS	732	> 0.02	NO	NO
New Exp.	7500 + 3000	0.00005	YES	YES

Long baseline neutrino detector sites considered for CERN neutrino beams

- **Magic baseline**

  INO – Indian Neutrino Observatory, 2 sites considered:

  1. Ramman, N 27.4, E 88.1

  2. Pushep, N 11.5, E 76.6

  Distance to CERN for both ~ 7125 km

  INO is a very serious, well documented proposal of 2006 !!

- **The "~3000 km" baseline**

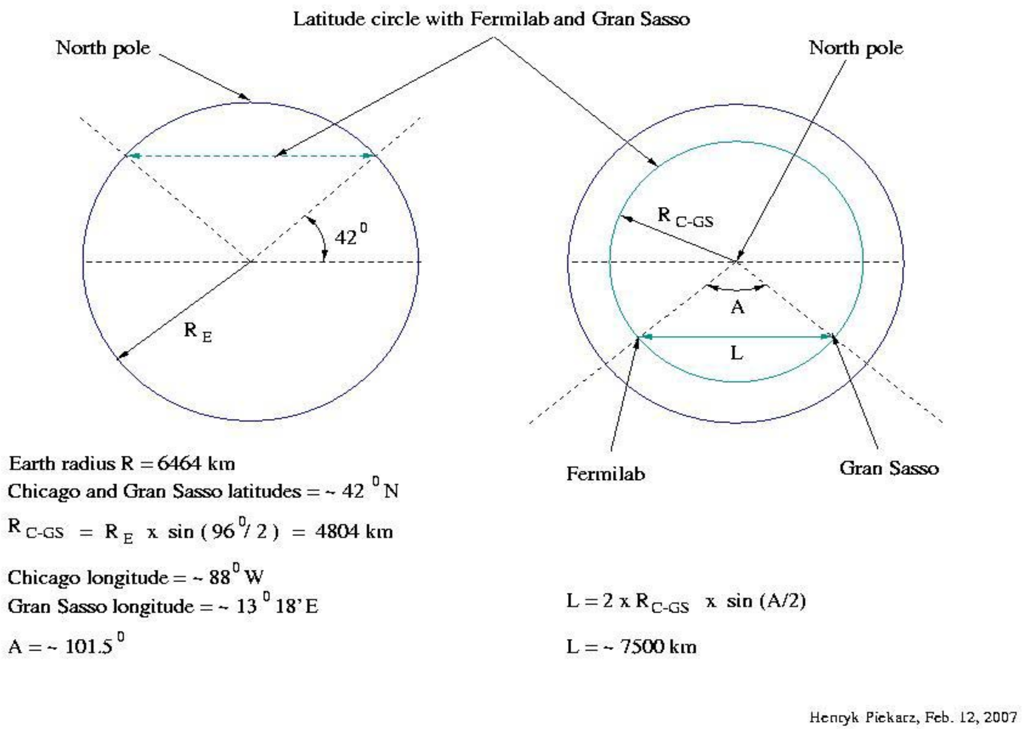
  - Santa Cruz (Canary Islands, Spain), 2750 km

  - Longyearbyen (Iceland, Norway), 3590 km

  - Pyhaesalami (Finland), 1995 km

Potential detector sites for 7500 km baseline from Fermilab

- Only in Europe (excluding permafrost region of Chukotka), e.g. Gran Sasso detector in Italy: ~750 km from CERN, and ~ 7500 km from Fermilab



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Potential detector site at ~ 3000 km

- The ~ 3000 km baseline must be found within US
- Mount Whitney: peak 4348 m, prominence ~ 3000 m, granite, non-seismic. At its foothill – city of Loan Pine, CA 93545 (airport, golf, hotels) => seems to be a perfect site for a neutrino detector at 2700 km away from FNAL

Baseline from FNAL to Loan Pine

Sierra Nevada Mountain Ridge with MT Whitney (center)

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Proton beam requirements for long baseline neutrino experiments

	Proton energy [GeV]	L [km]	E_{ν} [GeV]	POT/Y x 10^{19}	Limit $\sin^2 \theta_{13}$
FNAL NUMI	120	735	3	36	> 0.05
CERN CNGS	350	732	17.4	4.5	> 0.02

- Comparing NUMI to CNGS suggests that higher proton energy is advantageous in spite of much higher neutrino energy at CNGS adversely affecting oscillation probability
- In literature there are statements suggesting use of the highest possible proton beam momentum, but the limit projections are complicated by neutrino detection methods

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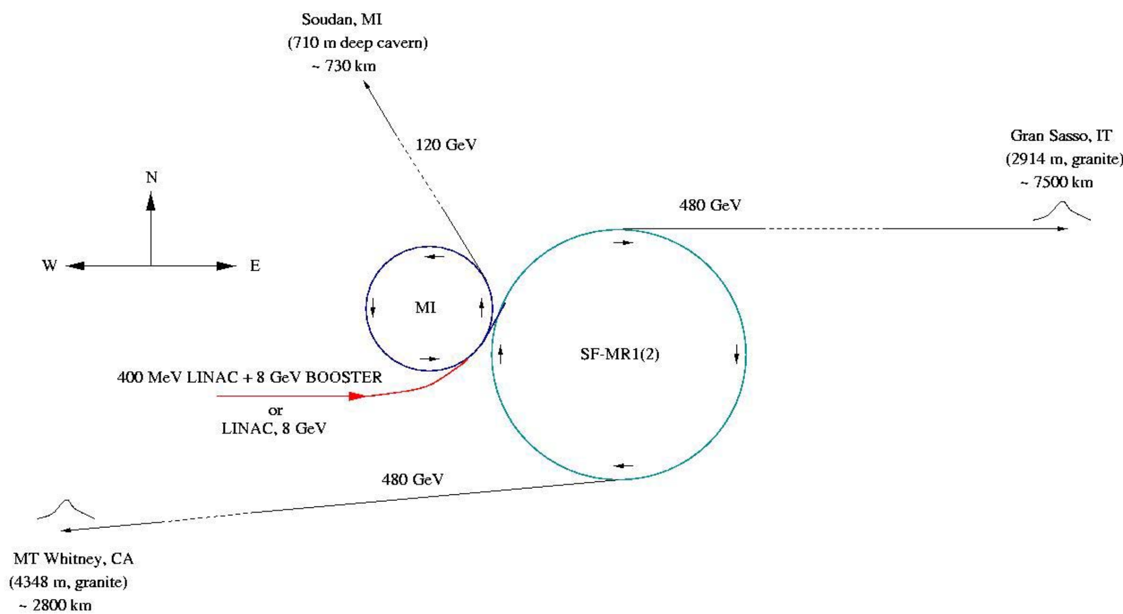
Proposed new Fermilab accelerator complex



- **Install two, 480 GeV, fast cycling accelerator rings in MR tunnel**
- **Extract proton beams onto two new neutrino production targets to produce interchangeably neutrino beams to Europe (e.g. Gran Sasso), and/or to Mt Whitney**
- **Operations for Soudan may continue while the DSF-MR is off (extraction line from the DSF-MR to NUMI is also possible)**

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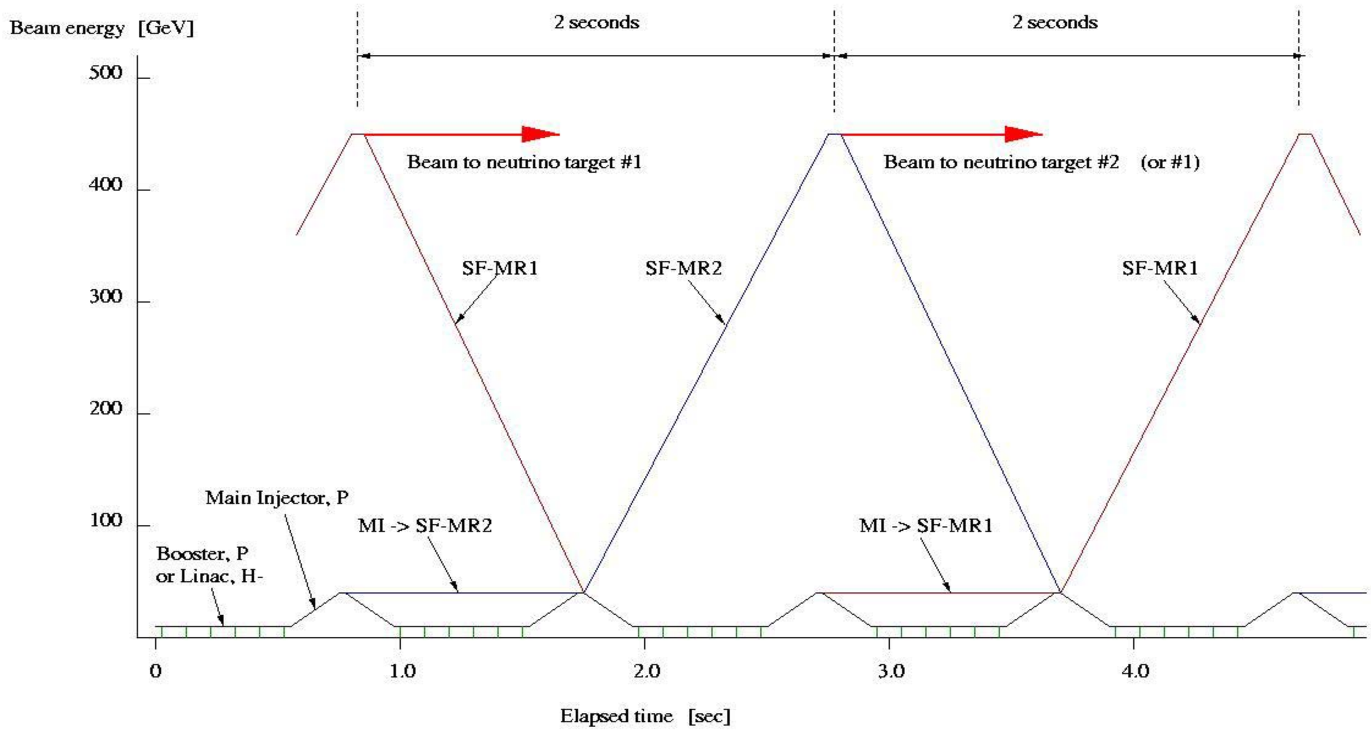
Operation & timing sequence for DSF-MR beams



- **LINAC and Main Injector will be "recharged" every second, and the SF-MR1 and SF-MR2 will receive beam every 2 seconds**

Proton energy and beam power on target with DSF-MR

Accelerator System	Ion Source Rep. Rate [Hz]	Pulse Length [msec]	Protons per Cycle x 10^{14}	Proton Energy [GeV]	Beam Power on Target [MW]
Present	15	0.09	0.45	8-120	0.40
Present + DSF-MR	15	0.09	0.90	45-480	3.20
Present + Accu. Stack + DSF-MR	15	0.09	1.66	45-450	5.90
8 GeV Linac + MI	10	1	1.5	8-120	0.5 (2.0)*

* Assuming feasibility of high-duty factor H- source

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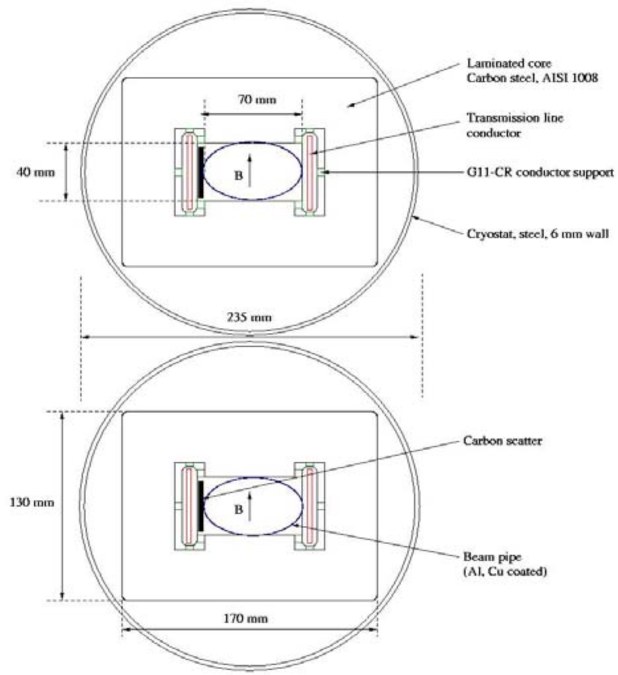
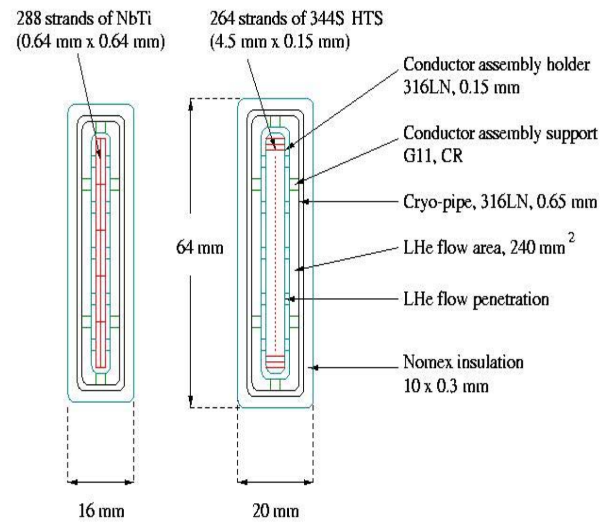
DSF-MR magnets





- **Proposed magnet and conductor options for the DSF-MR accelerator. Some details (magnetic design, Eddie currents effect, leads, power supply, cost, etc.) are presented in “LER and Fast Cycling SF-SPS”, Proceedings of LUMI-06 Conference dedicated to LHC luminosity**

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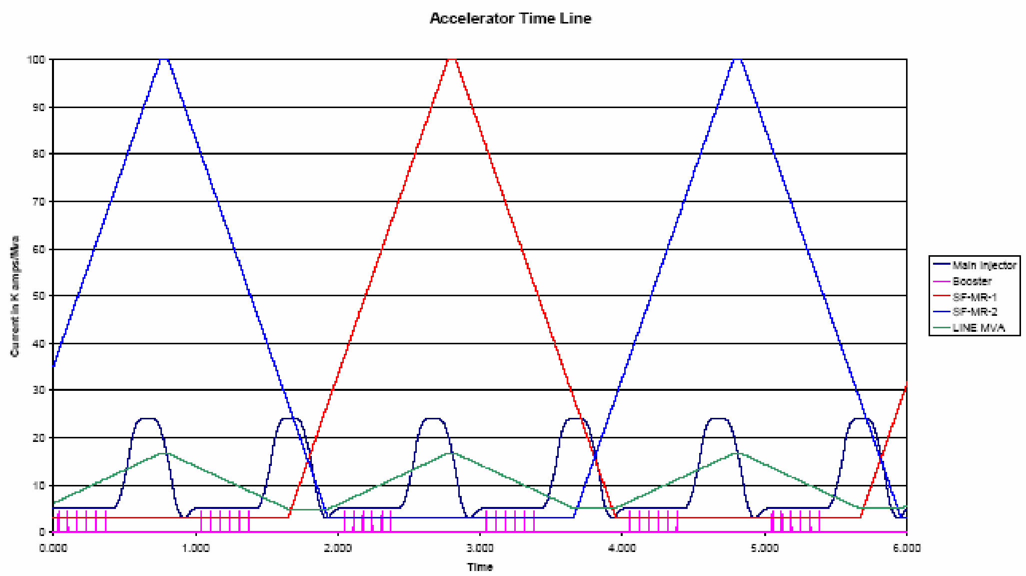
DSF-MR power systems



Each DSF-MR accelerator ring supply ramps out of phase allowing to share common harmonic filter and feeder systems.

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DSF-MR power, RF and cryogenic systems

- New power system will have to be developed for DSF-MR.

  Each accelerator ring supply will be +/- 2000 V ramping supply at 100,000 A current and 162 MVA peak power

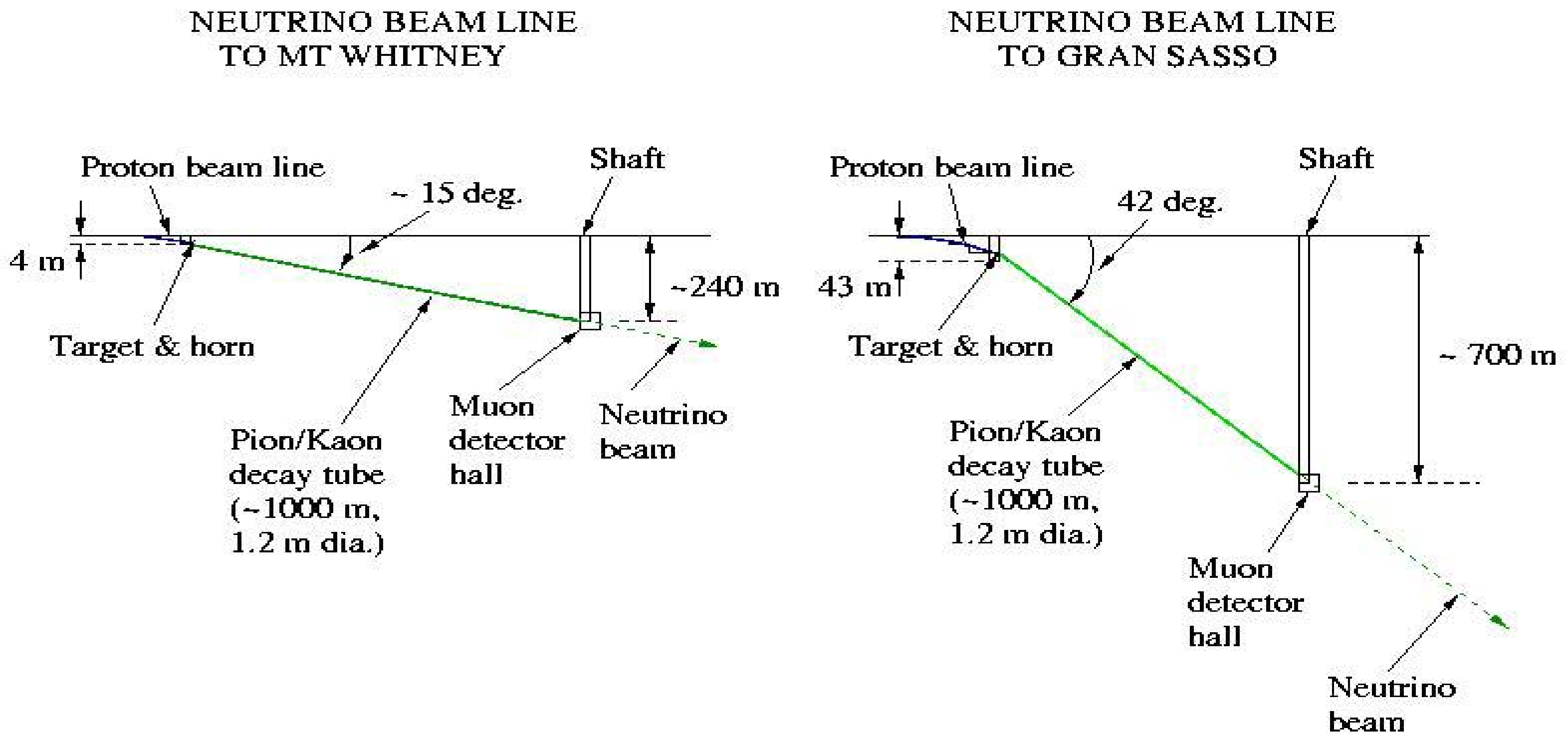
  Some equipment exists, and the present Tevatron power transformer of 40 MVA pulsed duty can support DSF-MR
- The Main Ring is already equipped with RF system for the Tevatron, but it must be seriously upgraded to meet the increased power demand for fast cycle of the DSF-MR
- The existing Tevatron cryogenic system will be used (with some modifications) for the DSF-MR magnets.

  The expected DSF-MR required refrigeration power is at ~(10-20)% of the Tevatron

Neutrino production lines

- **The strong descent of the proton lines to the production targets is a significant civil engineering challenge. Most of the beam path (~1000 m), however, is a decay tube of $\pi/K \rightarrow \mu + \nu$. With 42^0 descending angle the neutrino target will have to be at depth of ~700 m. For comparison the Soudan detector is at ~ 700 m below the surface.**
- **The Tevatron may be used magnets to construct the transfer lines from DSF-MR to the neutrino production targets**

Neutrino production lines



Sketch of neutrino production lines for 2700 and 7500 km baselines

Cost estimate

Neutrino beams subsystems	[$M]
DSF-MR	300
Neutrino production lines	200
Targets and muon detection	50
Total	550
Contingency 30%	165
Grand total	720

Timeline

Activity	Time [Y]	Lapsed time [Y]
DSF-MR design	1	1
Magnet R&D	2	2
Power supply R&D	2	2
DSF-MR magnet production	3	5
Magnet rings installation	3	5
Neutrino beam lines	2	5
Neutrino targets	2	5
Neutrino detectors	2	5
DSF-MR commissioning	1	6

Summary & Conclusions

- **DSF-MR accelerator will allow:**
  - **open new opportunity for high expectations in particle physics research and possibly to probe particle mass scales well beyond SM with neutrino mass reach < 0.00005 eV**
  - **utilize and preserve the potential of Fermilab as major US/World HEP Institution for the next 2 decades**
- **The cost of DSF-MR is expected to be at ~ 10 % level of the projected Sub-TeV ILC, so it will not impede possible realization of the ILC, or other next HEP large scale project**